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THE OCCURRENCE OF LIGHTNING STORMS IN RELATION TO FOREST FIRES IN CALIFORNIA.

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[U. S. Forest Service, May 10, 1922.]

INTRODUCTION.

Thunderstorms and accompanying lightning are of course known by meteorologists and climatologists as a common phenomenon; the various types are recognized and described, and in Europe, at least, a certain amount of special study has been given them. In western North America, however, their general occurrence in the mountainous areas, far removed from centers of population, and consequently from the principal weather stations, has apparently resulted in rather minor attention to them by professional meteorologists. This is perfectly natural, since especially in California they have but a remote bearing on agriculture, commerce, or navigation, and study of them from any of these standpoints would be of rather academic interest.

The occurrence of these storms is, to be sure, noted by all weather observers of the United States Weather Bureau, and a steadily-accumulating mass of data has long been available, but until relatively recent years no particular reason has existed for careful study of this phenomenon.

Beginning with the creation of the national forests (formerly forest reserves) in California, however, professional foresters, at least, have been forced to a keen realization of the importance of electrical storms, and have been deeply interested in any contribution to our very meager knowledge of their formation, behavior, and action. From the moment that the national forests were put under administration, lightning has proved to be the principal single cause of forest fires in California, and, indeed, throughout the West. Plummer¹ and Palmer² have already pointed out the rôle of lightning as a cause of fires, and it is not our purpose to repeat the details of their comprehensive studies. Since the publication of Palmer's paper, lightning has continued to be a major cause of fires in California, varying in intensity from year to year, but never entirely absent. In the decade from 1911-1920, inclusive, in the national forests of California, excluding those in southern California, lightning has been responsible for 4,363 out of a total of 10,527 fires, or 41.5 per cent. The other fires are the result of six causes (grouped as man-caused), and the most important of these is that of camper and smoker fires, numbering 2,239, or 21.3 per cent of the total.

During the decade just passed, a considerable mass of data concerning lightning fires has been collected by the United States Forest Service, merely by the reports on the individual fires from that cause. Since an analysis of these data will throw some light on an obscure sub-

ject, this paper is prepared in the hope that it may serve that purpose. It is proposed to treat, first, of the seasonal distribution of lightning fires; second, to analyze the special features from the standpoint of forest-fire protection, especially the characteristic bunching; third, to discuss and define the zones in which they occur; fourth, to study and plot the occurrence of some of the great individual storms of the past 10 years, and lastly to recapitulate the characteristics as affecting fire protection and to point out the special phases of study which appear of most importance and most worthy of attention.

Part of the material presented is unquestionably of less interest to meteorologists than to foresters, but is needed to form a connected story.

Foresters have a special and, perhaps, selfish interest in electrical storms, in that they are concerned with them only as they result in forest fires. So far as they care, lightning may play around the bare granite ridges of the high Sierra every day of the fire season, so long as the storms do not move down into the timber belt of lower altitudes. Lightning zones to them mean areas in which fires are set which spread and must be fought. The season of lightning danger is that in which the forest is dry enough to ignite.

SEASONAL DISTRIBUTION.

Whatever may be the seasonal distribution of lightning storms, lightning fires in California occur in a very concentrated form. This is well illustrated in Table 1, which shows number and per cent of total by months.

TABLE 1.—Seasonal distribution of lightning fires, 1911-1920.

Month.	May.	June.	July.	August.	September.	October.	Total.
Total number.....	109	498	1,436	1,939	381	50	4,363
Per cent of total number.....	2.5	11.4	32.8	44.3	7.6	1.4	100.0

The months of June, July, and August have 3,873, or 89 per cent of total, while July and August alone have 3,375, or 77 per cent. From the standpoint of fire protection the summer months are by far of the most importance. (See fig. 1.)

Figure 2 illustrates the seasonal distribution of lightning fires so far recorded. Due to the fact that only 10 years' records are available, the curve is not entirely regular, and it has therefore been smoothed to show the probable correct position. The rise to a peak and the equally sudden fall suggest a correlation with temperature changes; the second curve on the figure, therefore, represents the average mean monthly maxima for 39

¹ Plummer, Fred Gordon: Lightning in relation to forest fires. *Forest Service Bulletin* 111, 1912.

² Palmer, Andrew H.: Lightning and Forest Fires in California. *Mo. WEATHER REV.*, March, 1917, 99-103.

mountain and foothill stations in California having records of 10 years or more. At once it is evident that a reasonably close parallelism exists between the two, with a decided tendency for the fire curve to lag behind that for maximum temperatures. This lag is between a quarter and a half a month. Of course the occurrence of rain and the previous moisture condition of the forest floor affects the starting of lightning fires, particularly in June and September, but the conclusion seems fair that the number of lightning fires will increase as temperatures increase, and will decrease with temperature as well.

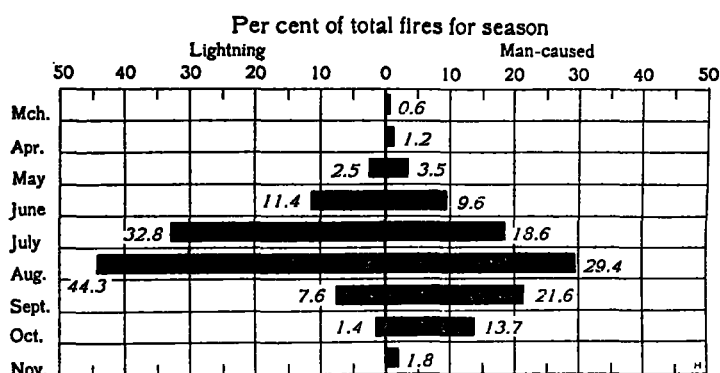


FIG. 1.—Relative percentage of lightning-caused and man-caused forest fires.

INTENSITY OF STORMS.

With the 10 years' data as a basis, a study has been made of individual storms from the standpoint of number of fires set per storm. The data are shown in Table 2.

TABLE 2.—Summary of individual storms.

Number of fires per storm.	Number of storms.	Total number of fires.	Per cent "C" fires (over 10 acres).	Size of average fire acres.	Per cent of total lightning fires.	Per cent of total fires per storm.
1-50.....	(1)	1,687	11.9	49	38.6	0.25
51-150.....	13	1,164	10.1	29	26.7	2.05
151-250.....	3	627	11.3	34	14.4	4.80
251-350.....	3	885	26.5	312	20.3	6.77
Total.....		4,363			100.0	
Average.....			14.3	95		

¹ Unknown.

An examination of the data shows that the great majority of storms result in less than 50 fires and are known to be rather local in scope. Storms of the greatest intensity so far experienced—from 251 to 350 fires—have occurred only three times in 10 years. However, study of the table shows that these extraordinary storms are the most disastrous to organized fire protection. Up to the point of 250 fires per storm class "C" fires (those over 10 acres) are held to a low per cent of the total number, and the size of the average fire is fairly low and shows no tendency to increase. But with the heavy storms, fires are so numerous that the existing protection forces are unable to handle all, and some cover large areas, as reflected in per cent of C's and size of average fire. Damage caused by fires varies as acreage burned, and cost of suppression naturally increases as size of average fire becomes greater.

A pressing need of foresters is the short period prediction of these heavy-lightning storms, so that the organization of suppression forces may be completed

before, instead of after, the fires start. The extreme intensity of lightning as affecting forest fires is well illustrated in Table 3, which shows for each of the years of the record the per cent of total number of fires due to the single heaviest storm.

TABLE 3.—Intensity of lightning by years.

Year.	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Average.
Number of fires worst storm.....	116	89	214	108	94	233	339	255	70	295	181
Total fires for year.....	246	204	691	413	295	388	794	529	181	621	436
Per cent of total in one storm.....	47	43	31	26	32	60	43	48	39	48	42

On the average, 42 per cent of an entire season's fires are caused by one storm, with a range for different years of 26 to 60 per cent. It needs little effort to picture the difficulty, with a limited number of men, of handling business in such concentrated form.

LIGHTNING ZONES.

It is, as has been pointed out, essential for foresters to know where lightning fires are likely to start, so that detection service may be organized to cover such areas, men may be placed in or near them, and other control measures taken. Experience in protection by the Forest Service shows that even within the timber belt, not all areas are subject to lightning fires. In order to deter-

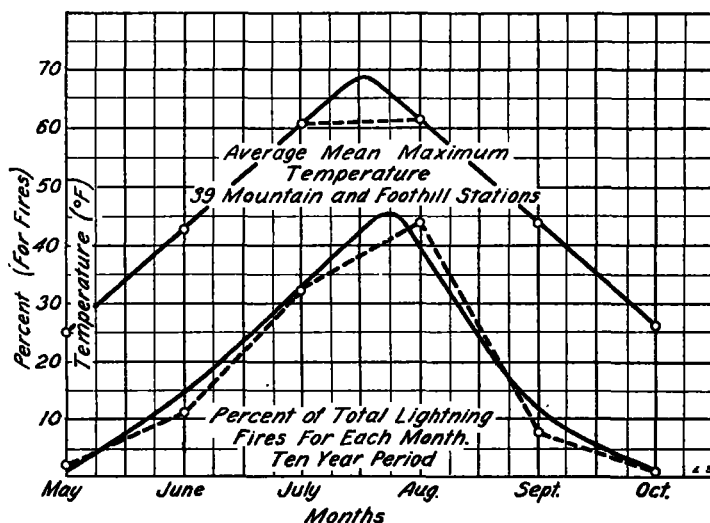


FIG. 2.—Relation between percentage of forest fires started by lightning and the average mean maximum temperature.

mine to what extent the idea of lightning zones is a reality, the starting point of each of the 4,363 lightning fires was plotted on a State map. At once it was evident that zones did exist and lines were drawn outlining these. Figure 3, which is reduced from the original map thus made, shows for the State of California the lightning fire zones in and adjacent to the national forests. For obvious reasons it is impossible to show each individual fire, but the intensity within the zone is indicated by broad classes, giving number of fires per township of lightning zone. Four intensities are recognized within the general lightning zone:

1. Less than 5 fires per township, classed as light intensity.
2. From 6 to 10 fires per township, classed as medium.

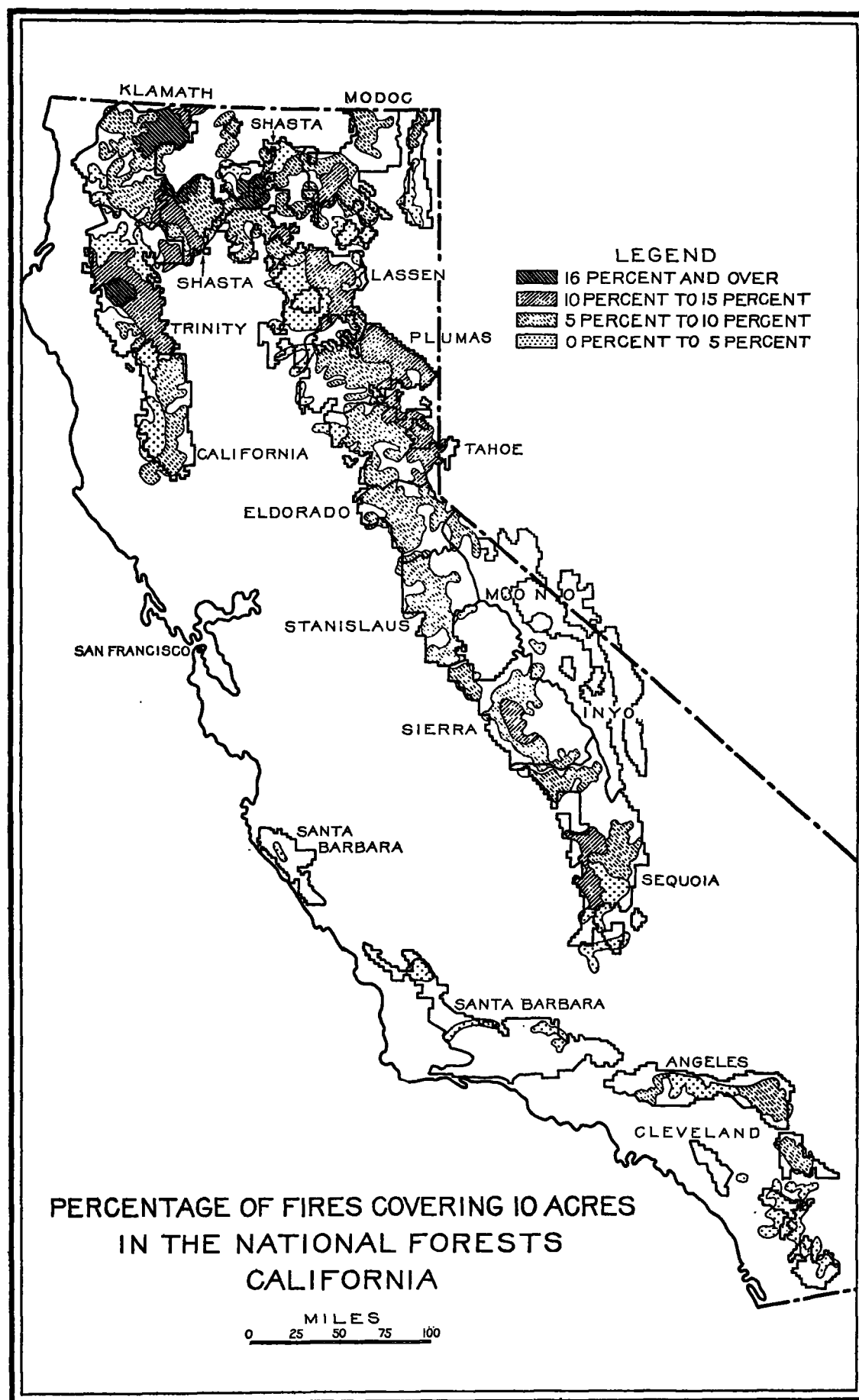
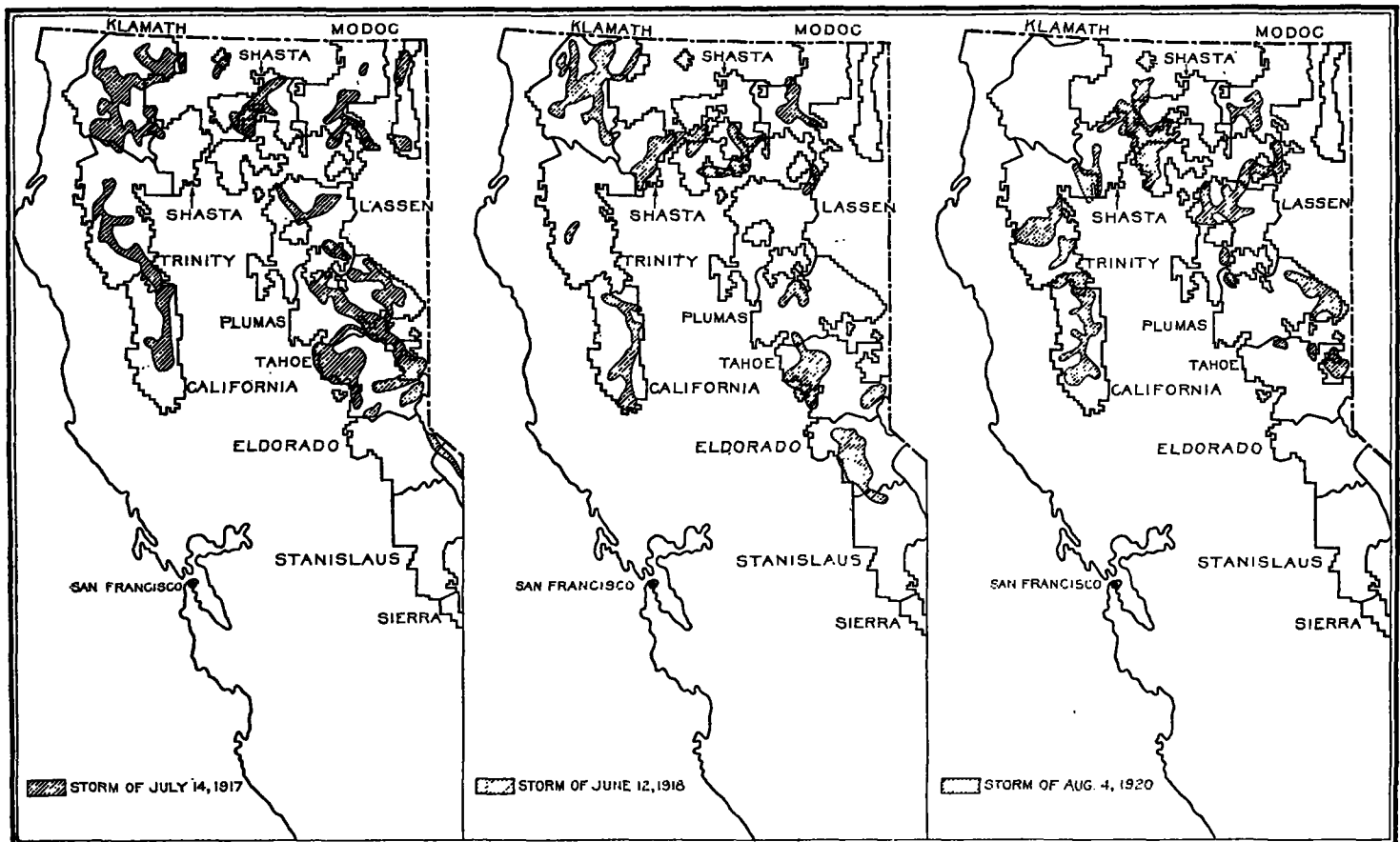


FIG. 3.



LOCATION OF LIGHTNING FIRES SET BY THREE STORMS IN THE NATIONAL FORESTS OF CALIFORNIA

FIG. 4.

3. From 11 to 15 fires per township, classed as heavy.

4. Over 15 fires per township, classed as very heavy.

Some very instructive relationships are evident:

1. From north to south in the Coast Ranges (Klamath, Trinity, and California National Forests) the zone tends to decrease in width.

2. The same general trend is apparent in the Sierra region, from the Shasta National Forest south. The narrowness of the belt on the Stanislaus Forest is due to the fact that for the Yosemite National Park no data on occurrence of fires are available, though they are known to occur in the western portion of the park.

3. Zones in the southern part of the State are generally narrower than in either the Coast Range or the Sierra.

4. Within the lightning fire zone number of fires per township generally decreases from north to south. Due probably to the relatively short period covered by the data and perhaps to incomplete reporting in some instances, this decrease is not entirely regular.

Using the different national forests as units, Table 4 presents the available data on relative size of lightning zone and concentration of fires within those zones.

This shows again the general decrease in intensity from north to south.

The statement may well be repeated that the lightning zones here defined and discussed are only those areas in which lightning causes forest fires that must be suppressed. The high Sierra of the Stanislaus, Sierra, and Sequoia National Forests, for example, is known to be subjected to very intense lightning storms, but due to the scarcity of tree growth and the general prevalence of high granite ridges, fires seldom result.

TABLE 4.—Lightning zone areas.

[Areas in thousands of acres.]

Forest.	Total area.	Area lightning zone.	Per cent of total area.	Total fires, 10 years.	Fires per 100,000 acres of lightning zone area.
Klamath.....	1,744	1,110	63.7	684	61.5
Trinity.....	1,746	1,042	59.7	499	47.9
Shasta.....	1,587	1,145	72.2	558	48.8
California.....	1,063	749	70.5	165	22.1
Total northern group.....	6,140	4,046	65.8	1,906	47.2
Modoc.....	1,583	895	56.5	334	37.2
Lassen.....	1,321	1,118	84.5	389	34.8
Total east side group.....	2,904	2,013	69.6	723	35.9
Plumas.....	1,433	922	64.3	484	52.4
Tahoe.....	1,271	1,032	81.3	312	30.2
Eldorado.....	836	425	50.8	189	44.5
Total north Sierra group....	3,540	2,379	69.8	985	39.7
Stanislaus.....	1,104	628	56.8	164	26.1
Sierra.....	1,683	674	40.5	250	37.1
Sequoia.....	2,022	1,090	53.9	335	30.7
Total south Sierra group....	4,789	2,392	49.9	749	31.3
Grand total.....	17,373	10,830	63.0	4,363	40.2

Figure 4 shows the areas in which fires were set by the three great general storms of July 16, 1917, June 12, 1918, and August 4, 1920.

It is to be noted that all three covered the same general region embracing the Siskiyou, the Coast Ranges south to Clear Lake, and the Sierras south to the southern end of the Eldorado National Forest, or well over half of

the entire national forest region of California. The August 4, 1920, storm did not apparently affect the extreme northwestern corner of the lightning zone, but elsewhere paralleled the others closely.

It is perfectly evident that the three storms did not cause fires in exactly the same spots, but their spheres of influence were similar enough so that future general storms of a like nature may be expected to repeat past history. Remembering the severe test to organized fire protection that these great storms represent, there can be little necessity to emphasize the need for short period prediction of such potential catastrophes.

CHARACTERISTICS OF LIGHTNING STORMS AND FIRES AS AFFECTING FOREST FIRE PROTECTION.

The previous discussion has pointed out certain features of lightning as affecting forest-fire protection. From the standpoint of the forester, the characters of most importance are:

1. The concentration of lightning fires both in time and place. Such fires occur in well-defined zones, and tend to occur in large numbers on single days. The tendency to bunching in location is a feature making for ease of control by suppression forces, since by a study of zone maps it is possible to locate fire guards in or near the areas on which fires are to be expected. The average distance to travel to fires is thus less than if they were distributed over the entire national forest area.

On the other hand, the tendency to occur in large numbers at one time makes for difficulty of control. Very frequently it happens that a single fire guard must handle several fires in one day, with consequently a high chance of some fires becoming large before suppression work can be commenced. The Forest Service under such conditions uses "emergency guards," i. e., responsible local stockmen, ranchers, miners, etc., hired for a few days to supplement the regular force who are employed for longer periods. Since, obviously, some time must elapse after the occurrence of a heavy storm before this second line of defense can be put in action, it follows that prediction of such storms for even a few hours in advance would materially speed up the attack on the resulting fires.

2. Most lightning storms are accompanied by rain in greater or less amount, the "dry" storm being rather uncommon. This characteristic is of importance in two respects. First, due to the rain, the litter and duff of the forest floor is normally damp, and lightning fires spread more slowly at the start than do fires from other causes. This, of course, makes for ease of control. Second, due to the same fact, many lightning fires, especially those set in standing snags (or dead trees), are unable to spread until the litter has dried out. Such fires, commonly termed "holdover," are often not discovered for several days after the storm. This feature is well shown in Table 5, which gives the per cent of lightning and man caused fires discovered within different lengths of elapsed time after their start.

TABLE 5.—*Relative speed of discovery of and travel to lightning and man caused fires, 1921.*

DISCOVERY.			TRAVEL.		
Length of time after start.	Per cent of total.		Length of time after start.	Per cent of total.	
	Lightning.	Man caused.		Lightning.	Man caused.
0 to 15 minutes.....	13	36	0 to 15 minutes.....	9	30
15 to 30 minutes.....	5	14	15 to 30 minutes.....	11	17
30 minutes to 1 hour.....	6	11	30 minutes to 1 hour.....	14	21
1 to 6 hours.....	8	15	1 to 4 hours.....	45	25
6 to 24 hours.....	35	10	4 to 24 hours.....	21	7
Over 24 hours.....	33	4	Total.....	100	100
Total.....	100	100			

It is seen that on the average man caused fires are discovered more promptly than lightning; i. e., they start spreading sooner after they are set. Within one hour after start 61 per cent of all man caused fires have been discovered, while in the same period only 24 per cent of lightning fires are found.

The table also shows the relative inaccessibility of lightning as compared to man caused fires as indicated by length of time required for suppression forces to reach them. Within one hour of travel time 68 per cent of all man caused fires are reached, while in the same length of elapsed time but 34 per cent of lightning fires can be attacked. This difference is, of course, due to the well-known fact that man caused fires tend to occur along main routes of travel, while lightning fires characteristically occur on high and inaccessible ridges, where travel must be on horseback or on foot.

This characteristic holding over of lightning fires, of course, works in two ways. It often reduces the peak load that must be handled immediately following a storm, but, on the other hand, there is always an element of uncertainty as to whether or not the crop of fires resulting from a storm has been cleaned up. The holdover fires often break out at unexpected times after the forest has again dried out, and spread rapidly, making for difficulty of control.

Evidently the lightning fires go a longer time unattended than do man caused, and from the fire-control standpoint this is a fairly constant characteristic.

NEEDED STUDY OF LIGHTNING STORMS.

From this sketch of lightning as a major cause of forest fires, it seems evident that study along the following general lines is needed and offers promise of important contributions to our imperfect knowledge of the subject:

1. Formation and movement of individual storms to determine the centers of formation that are believed to exist, the paths followed, etc. Such a study should aid in short period prediction of occurrence of storms in specific localities. The results will be of particular value in connection with the great general storms, which may affect almost an entire State, or perhaps even more than one State.

2. The relation of general weather conditions to the occurrence of storms, especially the general storms. A correlative study of selected heavy storms of the past decade in relation to the weather maps preceding and during these storms appears to be distinctly worth while. From the standpoint of forest-fire control, the prediction of impending storms is of immense importance and the line of investigation suggested should not be neglected.

The study suggested in (1) above has already been undertaken by the Forest Service in California, in 1921, using the men on lookout points as observers. These men, located during the fire season on commanding points, have a unique opportunity to record data on lightning storms. The preliminary work suggests strongly that such data will be of high value. In 1922 it is planned to continue the study.

SUMMARY.

This study of lightning as an important factor in forest-fire control indicates that—

1. The seasonal distribution of lightning fires is highly concentrated, 77 per cent of the total occurring in July and August and 89 per cent in June, July, and August.

2. The seasonal distribution follows closely the course of mean maximum temperatures from month to month.

3. The number of fires set per storm ranges from a few up to nearly 350.

4. Well-defined zones of lightning fires are found to exist in the national forests. Both the relative area of the lightning zone compared to total national forest area, and intensity of fires within that zone are found to decrease, though by no means regularly, from north to south.

5. In general, the regions affected by the three very heavy storms of the past decade correspond.

6. Lightning fires have certain characteristics differentiating them from man caused fires, chief of which are bunching, slow spread at start, and inaccessibility. These affect methods of forest-fire control.

7. An investigation of this important phenomenon is now under way, and further study is needed.

DISCUSSION OF THUNDERSTORMS AND FOREST FIRES IN CALIFORNIA.

By E. A. BEALS, District Forecaster.

[Weather Bureau Office, San Francisco, Calif., April 13, 1923.]

Unfortunately the Weather Bureau has no regular stations reporting by telegraph in the forested areas of California. There are a number of cooperative stations in these regions, but the data obtained from them are very meager. No continuous records of pressure, temperature, humidity, evaporation, wind direction and force have been kept in the forests of California, except possibly sporadically at a few places by the United States Forest Service. Also there are no records of cloud characteristics and their movements. It is quite necessary in order to predict weather phenomena that the forecasters should have available as much information as possible about the weather that is liable to occur in the region for which he makes predictions. This is all the more necessary when the prediction is for a limited area, and for a rather slight change in one or two elements. The foresters want forecasts of drying north winds, of high temperature, and of local or heat thunderstorms. Information regarding these phenomena are wanted as far in advance as possible so they can strengthen their fire-fighting forces, and place them in advantageous positions to combat the fires which they know at such times occur most frequently.

Forests are mostly in mountainous regions, and the surface winds do not always obey the barometric gradients in such localities. The winds blow up and down the canyons, in whatever direction they happen to lie, unless of extraordinary force, when they follow more closely the barometric gradients. To cause the spread of a forest fire the winds need not be very strong; an increase from light (8 to 13 miles an hour) to moderate (18 to 23 miles an hour) is ample to produce a great conflagration. After the fire once gets a good start, it causes inflowing winds that sometimes reach hurricane force without the barometer at outlying stations giving any indication that winds of such force are blowing in that neighborhood.

As to information regarding high temperatures, these phenomena in California generally are of slow growth. The temperature rises from 4° to 6° daily until the thermometer in the valleys reaches about 100°, when it fluctuates to the extent of two or three degrees up or down, until an offshoot from an Arizona Low moves northeastward. This causes a sudden drop in temperature that lasts for two or three days, when the temperature again begins to slowly rise as before. It is not difficult to predict these hot spells; but we are not always certain as to their duration. One may start without going very far before the break occurs, and that is the great difficulty in predicting them, for, to meet the requirements, it really means a long-range prediction of several days.

Regarding local thunderstorms, weather maps are presented (fig. 1) showing the conditions the evenings before, and on the mornings of the dates when forest fires

due to lightning were unusually numerous in California. It will be noticed that there is a great similarity in the weather maps for the different years. In each a trough-shaped low-pressure area extends from Arizona northward through California, and on July 16, 1917, and on August 4, 1920, there is a small high-pressure area over Nevada. All the charts show a high impinging on the North Pacific coast.

This type of weather map is frequently in evidence during midsummer, and the difficulty in predicting thunderstorms is that so far as known they occur with this type in just about 50 per cent of cases.

Table 1 shows the temperature for seven days preceding the day when forest fires due to lightning were most troublesome, on that day, and for the two following days. These temperatures of course were taken at stations at the bottom of the valleys in California, and on the plateau on the east side of the Sierra Nevada Mountains. None is representative of the temperatures that actually occurred in the forested areas. They show in a general way a gradual increase in temperature up to the day when lightning fires were most numerous, with a change to cooler either on the days when the fires were most numerous or a day or two later.

TABLE 1.—Maximum temperatures.

[Dates of numerous fires due to lightning are inclosed between heavy rules.]

Stations.	July, 1917.									
	9	10	11	12	13	14	15	16	17	18
Red Bluff.....	98	102	110	110	106	98	110	100	102	100
Sacramento.....	92	102	106	100	98	94	98	92	96	96
Fresno.....	98	104	106	108	108	106	106	106	106	100
Reno.....	88	94	102	100	102	96	96	88	92	92
Tonopah.....	90	92	94	96	94	94	92	88	90	90
	June, 1918.									
	5	6	7	8	9	10	11	12	13	14
Red Bluff.....	94	96	100	100	102	104	110	92	96	96
Sacramento.....	92	90	90	88	100	102	108	96	90	88
Fresno.....	98	94	92	100	106	102	104	104	100	90
Reno.....	88	88	90	92	90	96	94	94	88	86
Tonopah.....	82	82	84	84	88	90	92	92	92	90
	July and August, 1920.									
	28	29	30	31	1	2	3	4	5	6
Red Bluff.....	96	96	96	102	100	100	100	96	96	104
Sacramento.....	88	92	94	100	98	94	94	90	92	100
Fresno.....	100	98	98	102	104	102	102	102	96	100
Reno.....	90	88	92	92	96	92	92	88	90	94
Tonopah.....	90	90	90	92	90	88	80	82	86	88

¹ Absolute highest.